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LIQUID CRYSTAL TELEVISION RECEIVERS APPLIED TO OPTICAL PATTERN RECOGNITION AND DNA REQUENCE ANALYSIS

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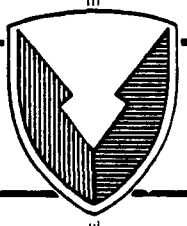

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This research is directed toward optical DNA sequence analysis, which is a specific application of high resolution, optical pattern recognition. The response times and contrast ratios of four different liquid crystal televisions were measured. The use of liquid crystal television in both a joint transform correlator and a VanderLugt correlator was investigated experimentally and was compared with the used of photographic film to search for a character within a data set of characters.

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I. INTRODUCTION

One potential application of optical pattern recognition (OPR) is the analysis of DNA sequence information. A complete discussion of this application and the results of some preliminary experiments have been given by Gildner [1]. Martin [2] has explored the choice of characters to represent the purines and pyrimidines, making up the DNA sequence, in order to optimize auto and cross correlations and minimize false correlations. The work presented here looks at a hardware aspect of the problem important to further experiments aimed at the practical application of OPR techniques to DNA sequence analysis.

Since the DNA sequences to be scanned already number in the millions and will eventually number in the billions, it is desirable to be able to scan the bases as rapidly as possible. Photographic film (35 mm slides) is presently used to input symbols and sequence information into the optical correlator and holographic film plates (Type 649F or equivalent) are used to make the matched filters. Processing of photographic film is tedious and time consuming. Gregory [3] has investigated the use of an inexpensive, Liquid Crystal Television receiver (LCTV) as a means to introduce information into an optical correlator in real time. Yu [4] has shown that LCTVs may be used as adaptive matched filters in a joint transform optical correlator. The question this work seeks to answer is whether LCTVs may be used to rapidly input sequence information into an optical correlator and whether LCTVs may be used as adaptive matched filters in such a correlator.

II. RESPONSE TIME AND CONTRAST OF LCTVs

In order to give a recognizable image when used as a television receiver, the LCTV must respond at least close to the TV frame rate of 30 per second. Although some screen persistence helps fool the human eye into seeing motion as continuous, there have been indications that LCTVs may be somewhat more sluggish in response to changes in video input than are normal TV phosphors. In addition, LCTV screens are never totally transmissive or totally opaque so contrast becomes an important consideration in high resolution pattern recognition. Four entirely different LCTVs were available within the Photonics Section for evaluation and comparison.

The experimental arrangement for measuring the response of the liquid crystal television (LCTV) receivers is shown in Figure 1. Light (632.8 nm) from the HeTHe laser (Uniphase Model 1107P) passed through a quarter wave plate, a spatial filter (10 micron pinhole), a collimating lens (250 mm fl), and an iris (not shown) which limited the collimated beam to a diameter slightly larger than that of the detector (113 mm). The beam splitter cube reflected roughly half the beam intensity through the shutter (Uniblitz) with Model SD–10 drive timer) to the CCD camera (RCA Model TC 1160). The collimated beam into the camera, limited to a diameter of 63 mm by the shutter aperture, almost spanned the height of the CCD array. The video output of the camera became the video input to the LCTVs so that, with the shutter open, their screens were almost filled with a large white circle. Only the Seiko had no video input jack, thus the camera video output was R.F. modulated and fed into the antenna jack.

The beam transmitted by the beam splitter passed through the center of the LCTV screen to the detector (NRC Model 815 photosensor). Polaroids P_1 and P_2 replaced the very poor polarizers which were removed from the liquid crystal sandwich. The LCTVs were further modified so that their screens were permanently fixed in the upright position. The output voltage from the power meter (NRC Model 815) was sampled and stored every millisecond by the computer.

After each run, the computer generated plots of output voltage from the power meter versus time for desired time segments.

Each LCTV was adjusted to maximize the difference between transmission, with the shutter open, and absorption, with the shutter closed. This maximization of bright to dark contrast was achieved through the adjustments of the quarter wave plate, polarizers P1 and P2, and the brightness control on the LCTV. With four interrelated adjustments it is impossible to be absolutely certain that each LCTV was operating at maximum contrast, but it is safe to say that each LCTV was operating with better contrast than "as delivered".

The computer was set to sample power meter output in volts 2000 times in two seconds. The shutter was opened by manual command sometime after the start of the two second sampling period and was closed by the timer after a preset interval; which could be varied from one to ten seconds. The camera, operating at the standard TV rate of 30 frames per second, limits the minimum of rise or fall time to about 33 ms.

Figure 2 shows a plot of voltage versus time for the Sharp Model 3ML 100 (BK) with the shutter open for 500 ms. The rise time is quite short (reaches 90% of maximum in 33 ms) but the decay time is much longer (approximately 160 ms decay constant*). The Sharp has a very small 60 Hz modulation voltage which can be seen mainly in the tail (1500–1700 ms) of Figure 2.

Figure 3 is a plot of power meter output voltage versus time for the Seiko Model LVD–202 with the shutter open for 150 ms. The 60 Hz modulation of the Seiko is much larger and consequently more obvious than the Sharp's modulation. The rise and decay times of the Seiko are somewhat shorter than those of the Sharp (rises to 100% of maximum in approximately 25 ms and decay constant of 37 ms).

Figure 4 shows a plot of the Casio Model 1200 with the shutter open for 350 ms. The modulation amplitude is much larger, the modulation frequency is somewhat slower (approximately 40 Hz), and the signal rises to about 75% of maximum in 33 ms (decay constant about 50 ms).

Figure 5 is a plot of the Citizen Model 03TA–OA (the only black and white LCTV tested) with the shutter open for 450 ms. The modulation, relative to the signal, is still larger and slower (approximately 15 Hz) and the signal rises to about 70% of maximum is 33 ms (decay constant about 120 ms).

Figure 6 was run to make certain that the detector/shutter combination did not account for any significant portion of the rise/fall times. The shutter was placed in front of the spatial filter in Figure 1 and no LCTV was in place. Polaroids P1 and P2 were adjusted to give about a one volt output from the power meter and the shutter was opened for 150 ms. The rise and fall times are both one millisecond as evidenced by the single data point recorded during rise and fall. In addition, the background reading of the power meter with no laser light falling on the detector is observed to be about 0.01 volt. Thus, if the LCTVs were blocking all the laser light, the shutter closed signal in Figures 2–5 should be about 0.01 volt.

Table 1 provides a quick comparison of the LCTVs tested. Column one is the percent of maximum voltage rise in 33 milliseconds. Column two is the decay time constant, column three is the "contrast ratio" defined as the average voltage shutter open divided by the average voltage shutter closed, and column four is the signal to modulation ratio defined as:

$$\frac{\text{(avg. Voltage shutter open) – (avg. Voltage shutter closed)}}{\text{(peak–to–peak modulation amplitude in volts)}}$$

*Time to rise and fall within 1/e (63%) of its equilibrium value.

TABLE 1. Summary of LCTV Response:

	%Rise in 33 ms	Decay Time Constant	Contrast Ratio	S/M
Sharp	90	160ms	2.5:1	25 = 14db
Seiko	100	37 ms	4.4:1	7 = 8db
Casio	75	50 ms	1.5:1	0.5 = –3db
Citizen	70	120 ms	1.3:1	0.35 = –4db

III. JOINT TRANSFORM OPTICAL CORRELATOR

One advantage of the Joint Transform Correlator (JTC) is the fact that an LCTV can be used not only to input the characters to be searched but also as an adaptive matched filter of the search character. Hudson [5] lists three advantages of the JTC which are important in the application to DNA sequence analysis: (1) large space–bandwidth product; (2) capability of performing multi image cross correlation in real time; and (3) high optical resolution.

Figure 7 shows the JTC system used here. Following Hudson [5], the input scene to LCTV #1 was split into two parts rather than using a split screen LCTV or two LCTVs. The upper portion of the field of view consists of the search character and the lower portion of the screen consists of the character set to be searched. This is illustrated in Figure 8 where the grate pattern represents the search character, seeking either orientation of diagonal bars, and the bars below represent the character set to be searched.

The joint transform is formed at the focal point L_2 (fl = 876mm) in Figure 7. The microscope objective forms a magnified image of this joint transform on the sensors of TV camera #2. The image on camera becomes the video input to LCTV #2, which is the adaptive matched filter. The correlation spots are formed at the focal point of L_4 (fl = 629 mm), enlarged and imaged on the sensors of camera #3 by the microscope objective, and displayed on monitor #2.

The joint transform at the focal point of L_2 in Figure 7 is broken into an interference pattern due to the pixels of the LCTV. Some pixel interference patterns are shown in Figure 9. Each one of the pixel interference maxima is the joint transform of the patterns on the screen. The microscope objective actually selects only one of these pixel interference maxima to magnify and display on TV camera #2. The Sharp TV has six very strong interference and dozens of much weaker ones. Thus, selecting one of these interference maxima means that over five sixths of the light is being "thrown away". Actually it would be an advantage, in this application, if the pixels of the LCTV were not only smaller but randomly oriented. Many randomly oriented pixels would give the same interference pattern as one single pixel.

The slide of symbols shown in Figure 8 was actually made up from one of Gildner's [1] slides. Since this slide had been used in a VanderLugt correlator, it was possible to compare the operation of the joint transform correlator with the operation of a VanderLugt correlator. The grid of diagonal lines should autocorrelate with either of the diagonal line patterns and should exhibit weaker cross correlations with the horizontal and vertical lines.

When placed in the joint transform correlator with all but the far right column of Figure 8 blacked out, there are six (rather than five) well defined correlation spots. When all but the second column from the right in Figure 8 is blacked out, there should be an alternation of strong and weak correlations. This was not the case in practice. It was not possible to determine from the brightness of the correlation spots which spots were due to autocorrelations and which were due to cross correlations. There was considerable variation in the brightness of the spots, but it seemed to be completely unrelated to the pattern on the slide.

Finally, if all but two rows of Figure 8 are blacked out, each member of each row correlates with the corresponding member of the opposite row. Thus, instead of the expected 12 correlation spots (double the number for a single row), there are at least 18 correlation spots. Since each correlation spot also becomes much more diffuse and structured it is difficult to tell exactly how many individual correlations are present.

IV. VANDERLUGT OPTICAL CORRELATOR

A drawing of the VanderLugt system appears as Figure 10. As pointed out in the previous section, the Fourier transform plane is dominated by the Fraunhofer diffraction pattern due to the pixel structure of the LCTV. Rather than using a pinhole to isolate a few of the pixel orders, as did Gregory [3], matched filters were made using the very large number of orders contained within the reference beam.

The first input scene was a set of two H's, one above the other, which almost filled the TV screen vertically. Although several matched filters of the double H pattern showed good colors when illuminated by a flashlight, none of them exhibited a discernable correlation spot even due to the pixel pattern. Only the Sharp and Seiko TVs were used since they produce much sharper pictures than the other two.

The first excellent correlation spot was obtained for the pixel pattern of the Sharp with no power or video input supplied. With the inactive I–CTV in place, the quarter wave plate was rotated until the reading of a power meter, just behind the TV screen, showed a maximum reading. Polaroid P1 was removed and Polaroid P2 was rotated to a position of maximum object beam intensity at the photoplate. The correlation spot with this matched filter (on 649F film) was very sharp and well defined with no structure and surrounded by no noticeable noise. The location of the film holder also had to be very precise; touching the micrometer screw on the stage was enough to change the intensity of the spot. The LCTV, however, could be moved side to side or up and down with no change in the position of the correlation spot. It was quite obvious that this was the correlation with the pixel pattern. When the LCTV was removed the sharp correlation spot disappeared, but a large, bright, irregular spot appeared in a different position. This spot seemed to be due to general scattering of the laser beam by the matched filter.

The spoked wheel pattern was fed to the video input of the Sharp LCTV in such a way that it almost filled the screen. This gave a great deal more white portion than the double H pattern used previously. Polaroid P1 was replaced and adjusted so that the pattern was as sharp as possible and the background was as dark as possible. The Fourier transform pattern thus formed was much less intense than the ones produced with no signal or power to the I–CTV. Consequently, the reference beam intensity had to be reduced and the exposure time for matched filter was about six times longer.

A correlation spot for the spoked wheel pattern was found only after considerable searching with the film stage holding the matched filter. This correlation spot was very similar to the correlation spot obtained with the pixels alone – very specific location, very small spot, no noticeable structure to the spot, and no discernable noise around the spot. When the LCTV was moved up or down or side to side the correlation spot tracked along with it. When the spoked wheel pattern was moved, the correlation spot started to track but then quickly disappeared as part of the spoked wheel and started to disappear from the TV screen. The correlation spot returned when the spoked wheel pattern was carefully returned to its original position.

Finally, when the power and video input were removed from the LCTV, no correlation with the pixel pattern could be found. The removal of Polaroid P1 and aligning the spoked matched filter with the pixel pattern still showed no correlation spot. This result, if true, is very surprising because it would seem that the correlation with the pixel pattern would dominate no matter what scene appeared on the screen. However, this does agree with Gregory's observations. He noted that a 1 mm pinhole at the focus of the 178 mm transform lens would have passed many orders of the pixel pattern, yet was not a problem.

V. CONCLUSIONS

The pixel size and contrast ratio of commercially available LCTVs severely limits their application in high resolution optical pattern recognition. The patterns necessary for DNA sequence analysis are currently too complicated for accurate display on LCTVs in a joint transform correlator architecture. The parallel processing nature of the correlator is lost when images must be scanned (at video rate) in order to be resolved by the input modulator.

Spatial light modulators are available which have a much higher resolution than the inexpensive LCTVs investigated here. A resolution of 20/40 lp/mm over a 1 inch active area should be quite adequate for displaying the DNA symbols discussed in this report.

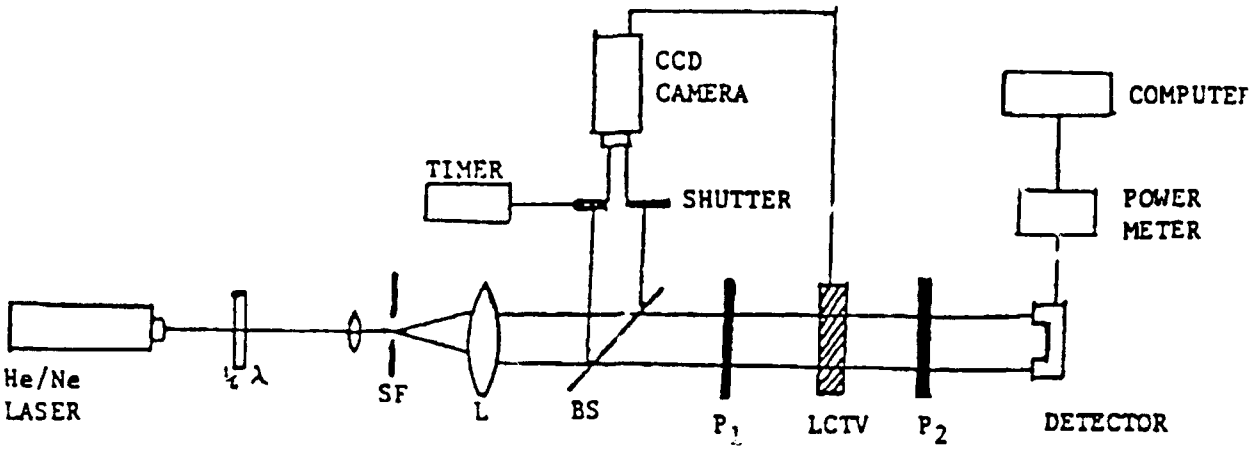

Figure 1. Experimental Arrangement for LCTV Response Measurements.

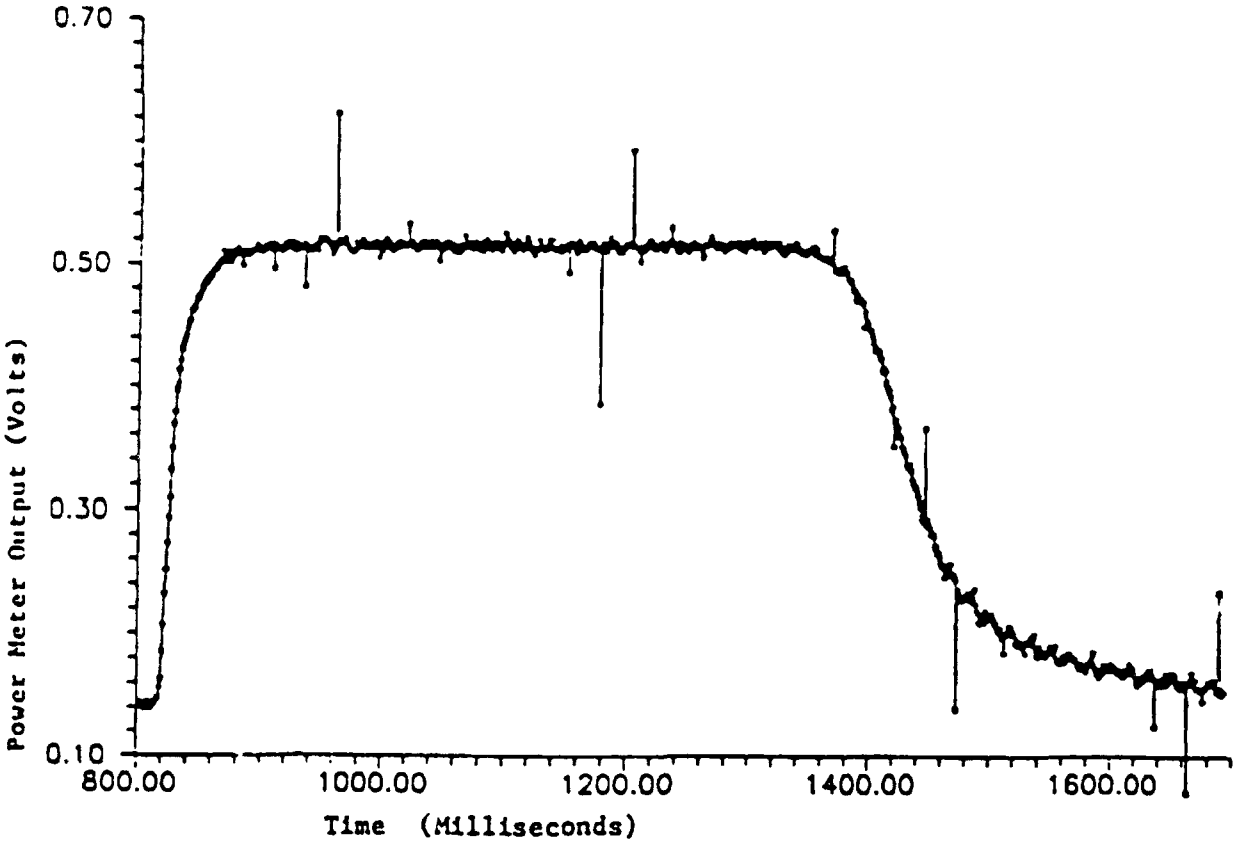

Figure 2. Response of the Sharp Model 3M1 100 (BK).

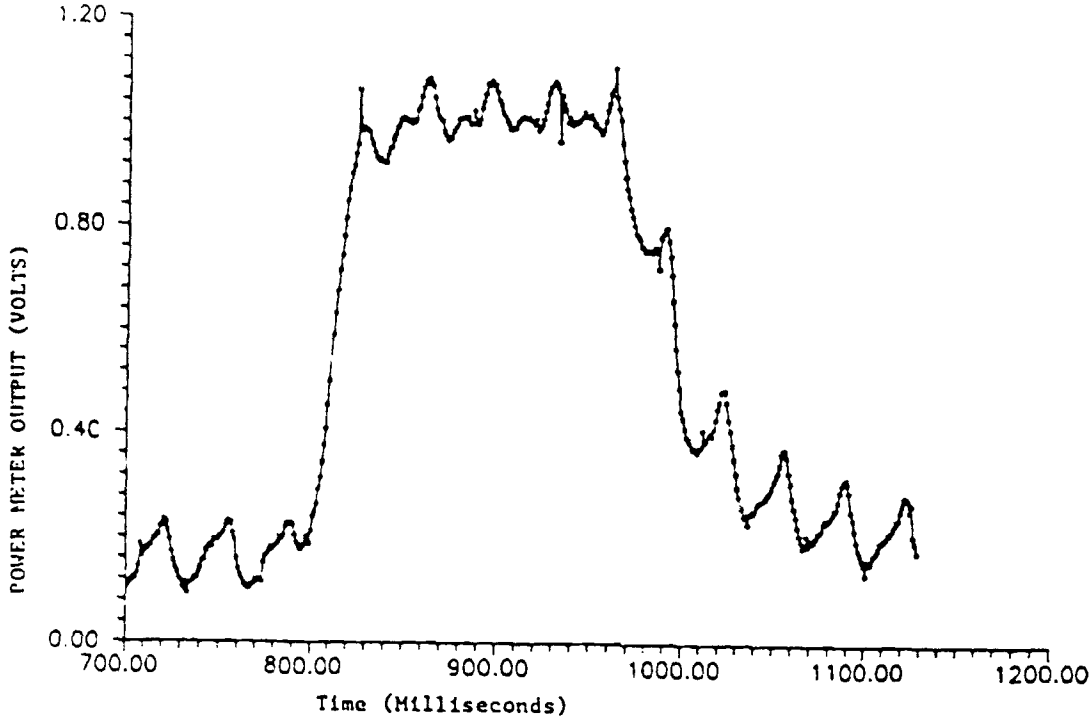

Figure 3. Response of the Seiko Model LVD–202.

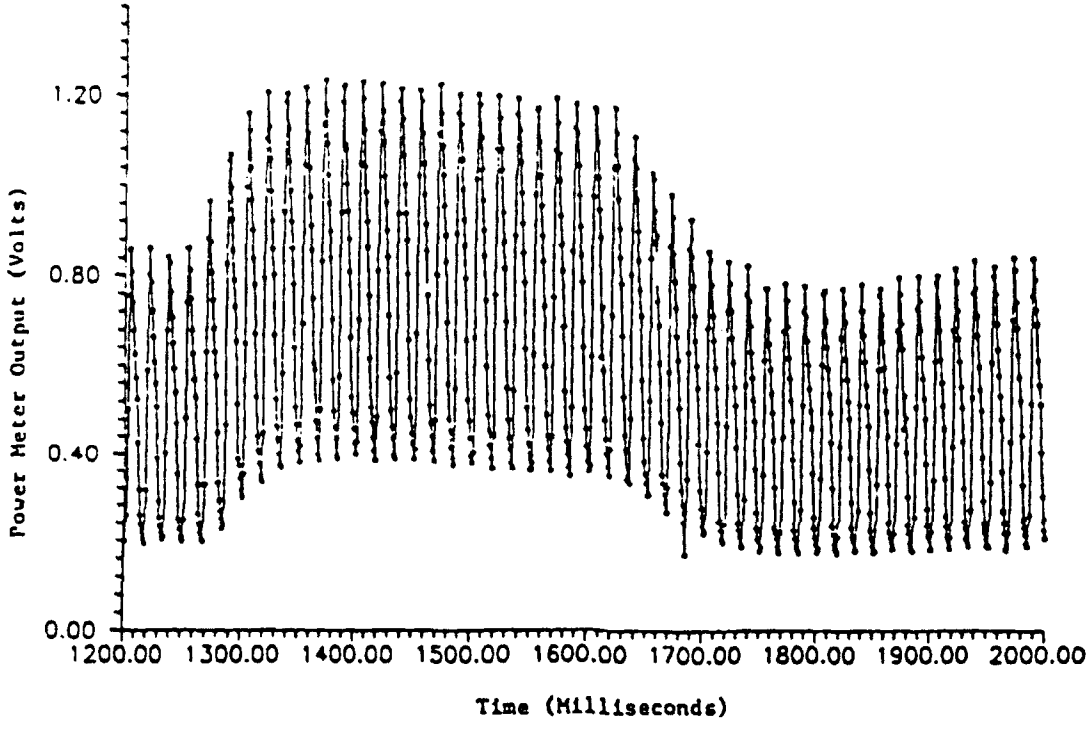

Figure 4. Response of the Casio Model 1200.

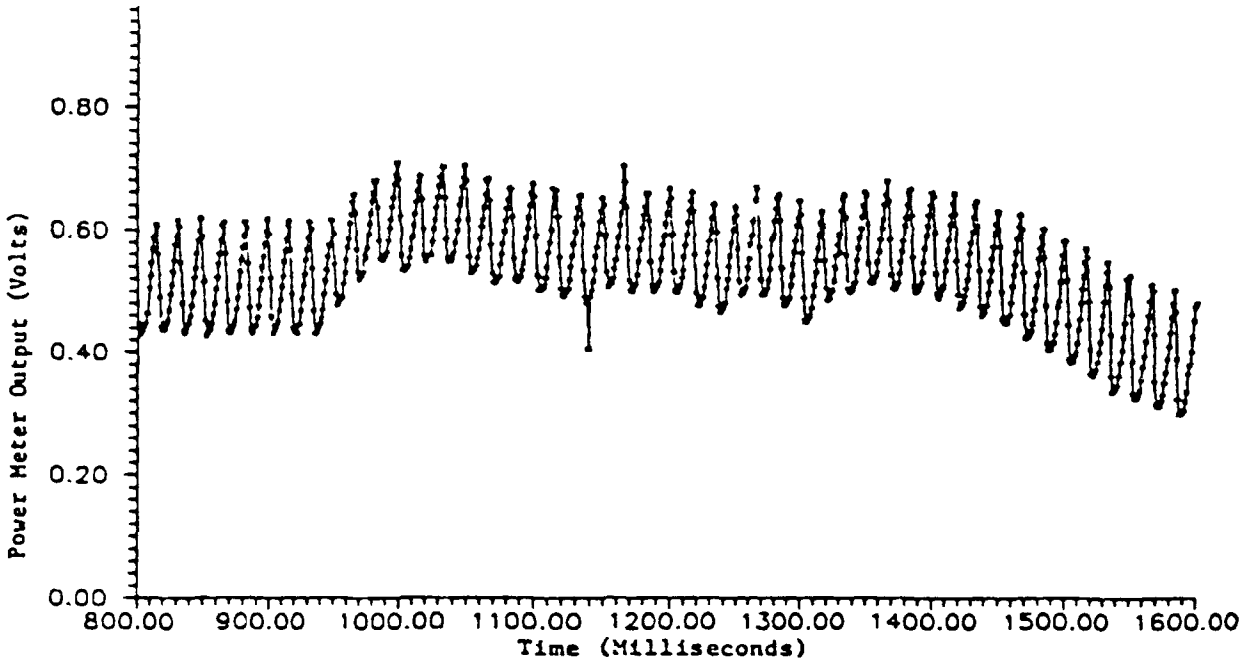

Figure 5. Response of the Citizen Model 03TA–OA.

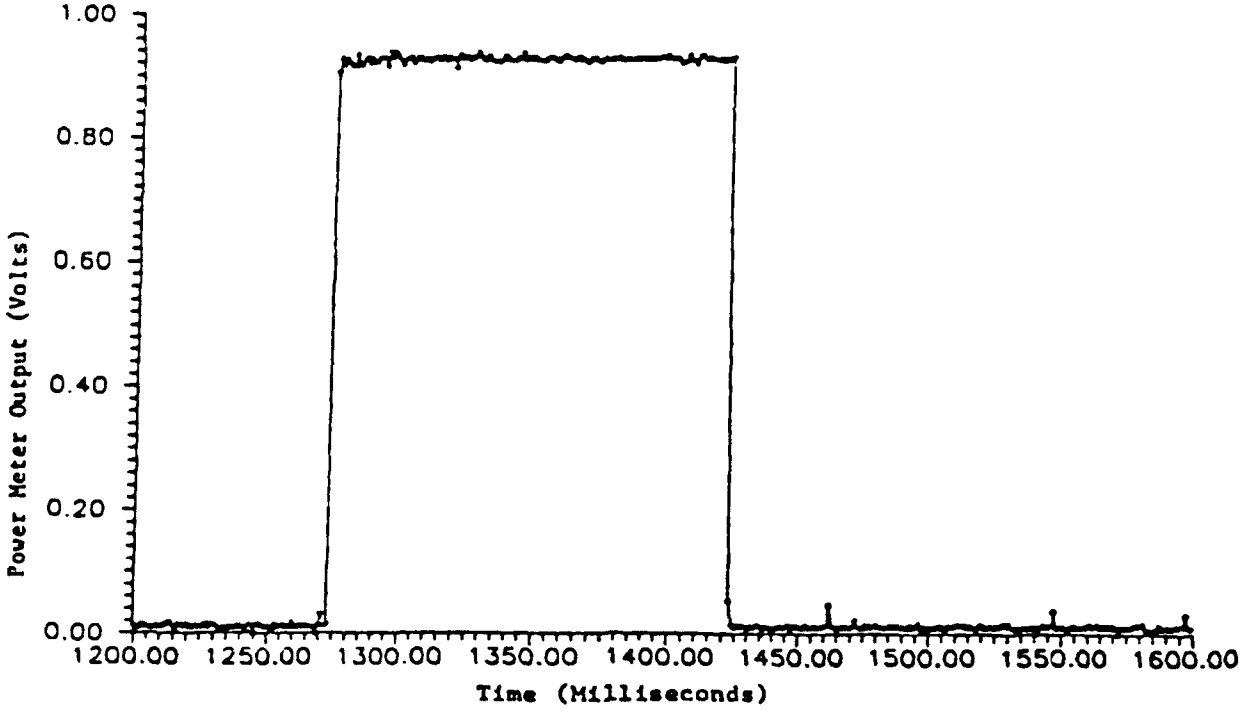

Figure 6. Response of the NRC Model 815 Photosensor.

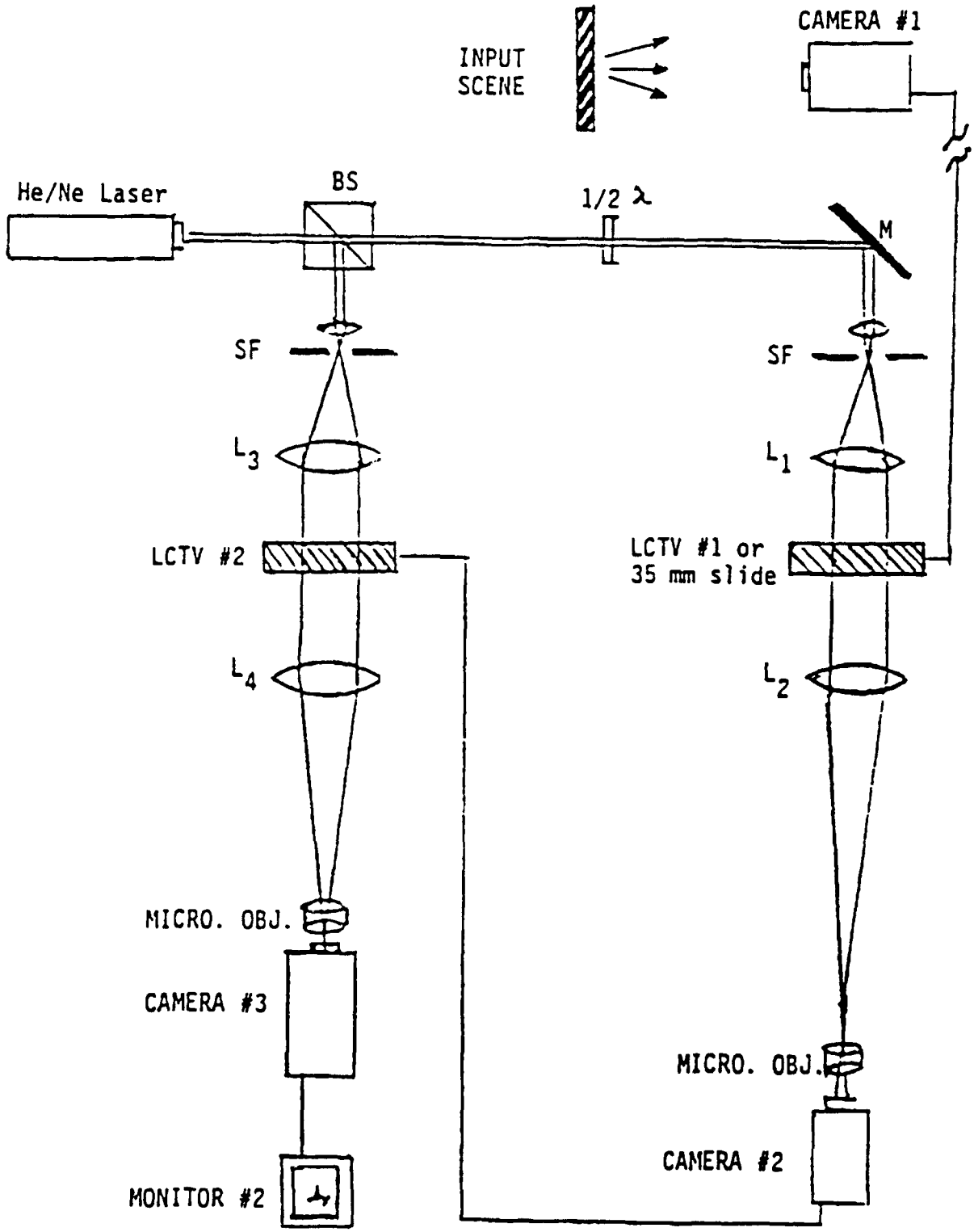

Figure 7. Joint Transform Correlator System.

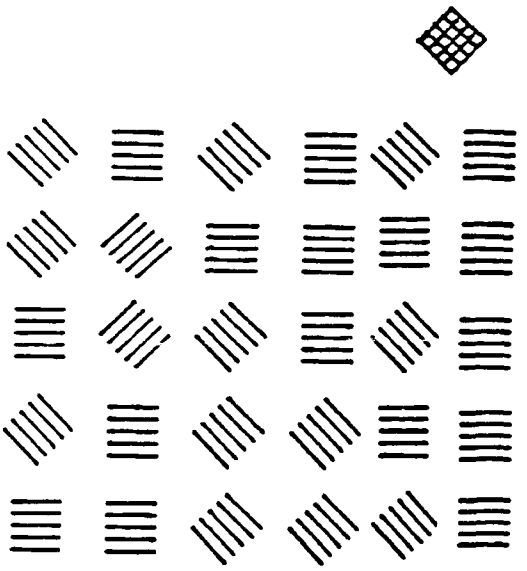

Figure 8. Input scene to the Joint Transform Correlator. The Grate is the Search Character and Bars are the Character Set to be Searched.

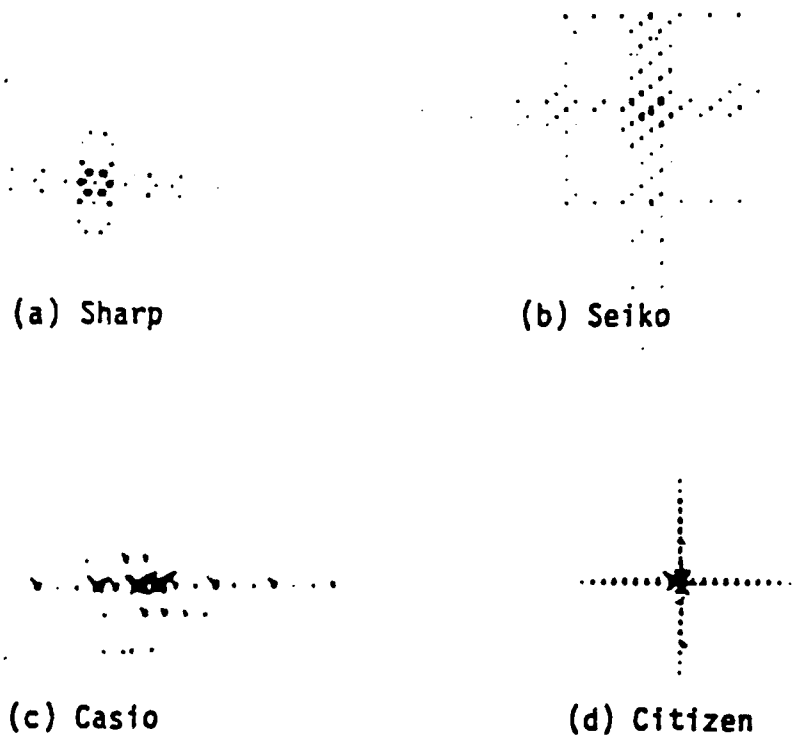

Figure 9. Fourier Transforms of the Pixel Structures of the Liquid Crystal Televisions. Focal Length of the Transform Lens is 876 mm.

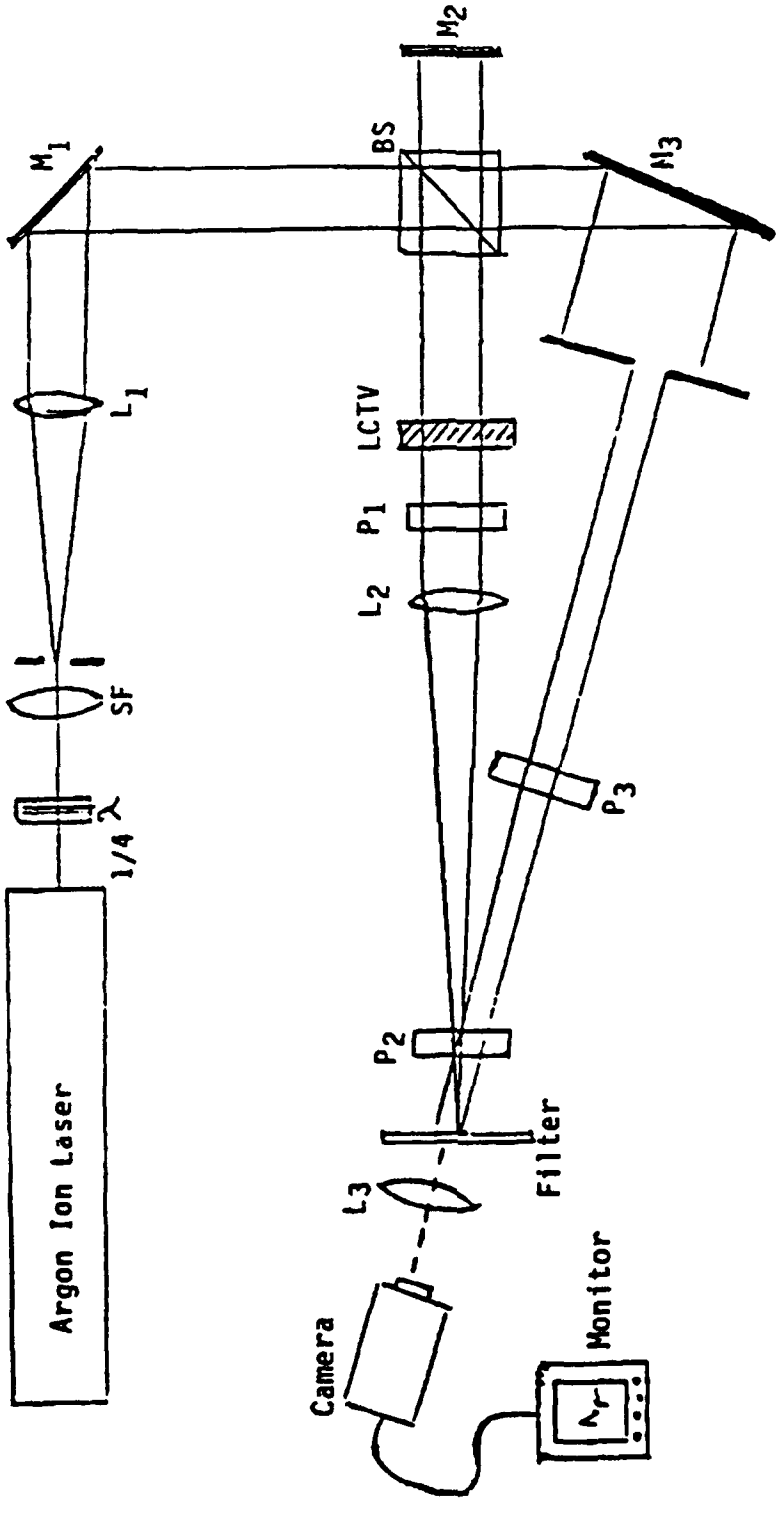

Figure 10. VanderLugt Correlator System. Focal Length of Transform Lens (L_2) is 876 mm.

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